A search for supernova neutrinos and constraint on the galactic star formation rate with the KamLAND data

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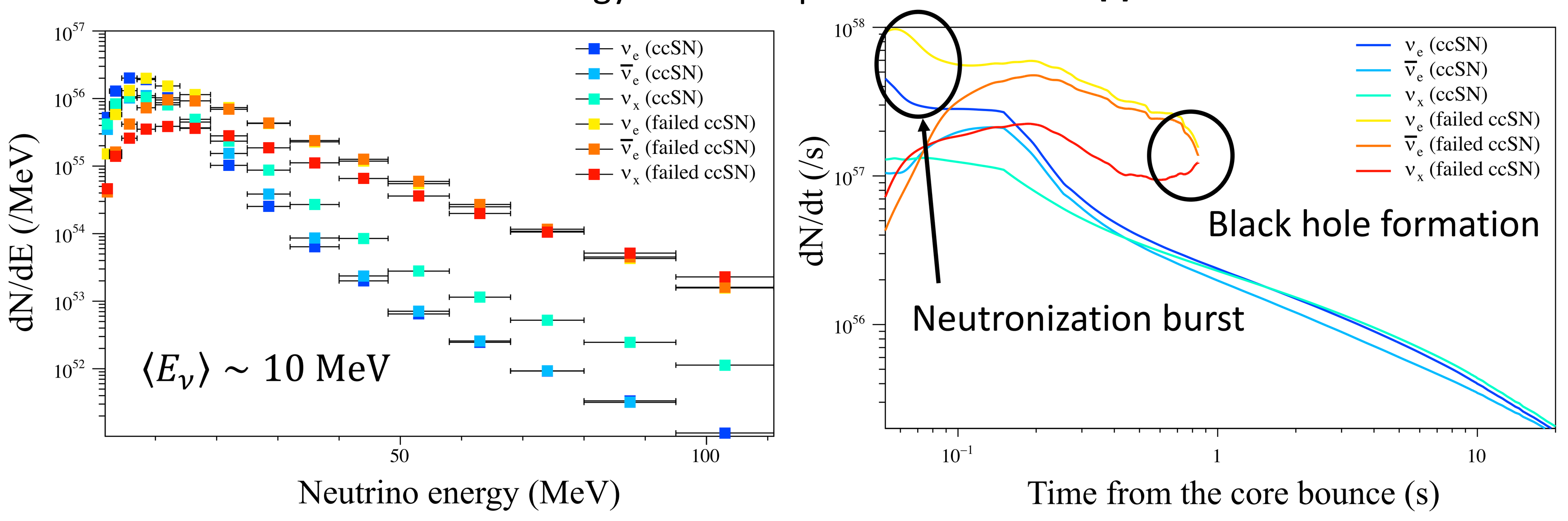
1. Introduction

Detecting supernova neutrinos (SNνs) reveals
detailed mechanisms of the supernova explosion / properties of the neutrino

Energy & time dependence of SNνs [1]



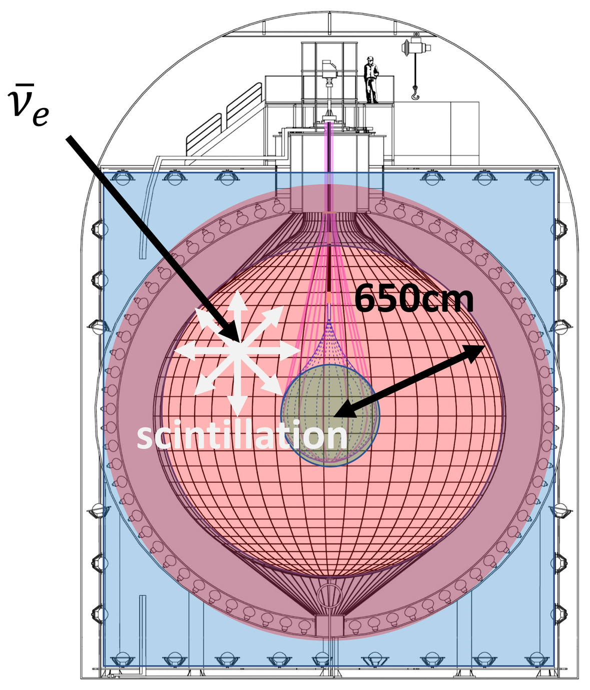
Predictions of the galactic SN rate: $\begin{cases} 0.032^{+0.073}_{-0.026}\ \mathrm{yr^{-1}} \text{ (astronomical obs.) [2]} \\ 0.0163 \pm 0.0046\ \mathrm{yr^{-1}} \text{ (include neutrino obs.) [3]} \end{cases}$

Supernova rate can be linked to the star formation rate (SFR).

We searched for SNνs and set constraint on the SFR.

[1]Nakazato et al. 2013
[2]Adams et al. 2013
[3]Rozwadowska et al. 2021

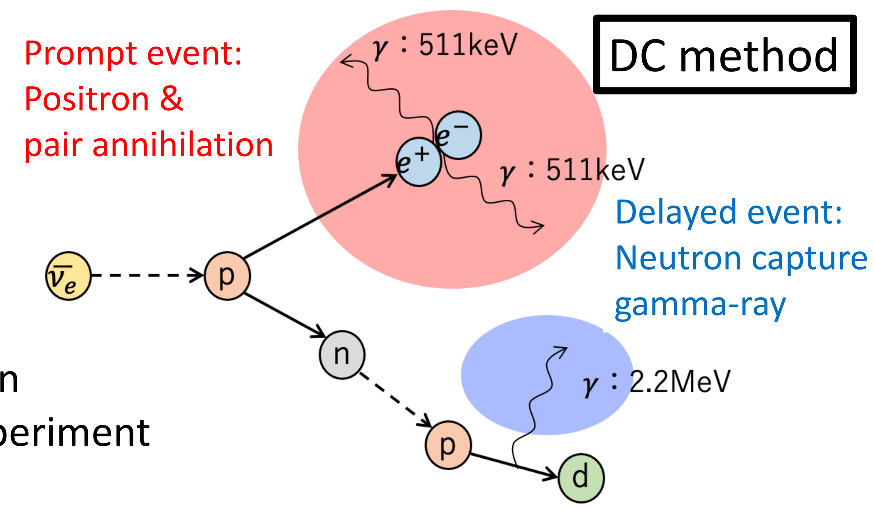
2. KamLAND detector



KamLAND detects $\bar{\nu}_e$ via the inverse beta decay ($\bar{\nu}_e p \rightarrow e^+ n$) using delayed coincidence (DC) method.

Advantages of KamLAND

1. Low background level due to the DC
2. Low energy threshold: $E_{\bar{\nu}_e} \geq 1.8$ MeV
3. High energy resolution: $6.4\%/\sqrt{E(\mathrm{MeV})}$
4. Long data-taking period: 2002/3/9–2020/4/25 (Livetime 5011.51 days)



Outer detector

- Water-Cherenkov detector for muon veto

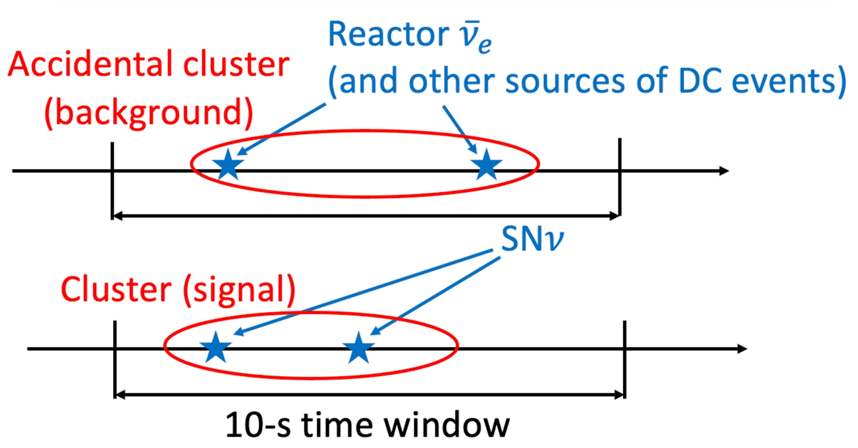
Inner detector

- Liquid scintillator for physics event detection
- ^{136}Xe loaded liquid scintillator for $0\nu\beta\beta$ experiment
- Radius cut $\leq$ 600 cm in this study

3. Selection criteria

For DC event

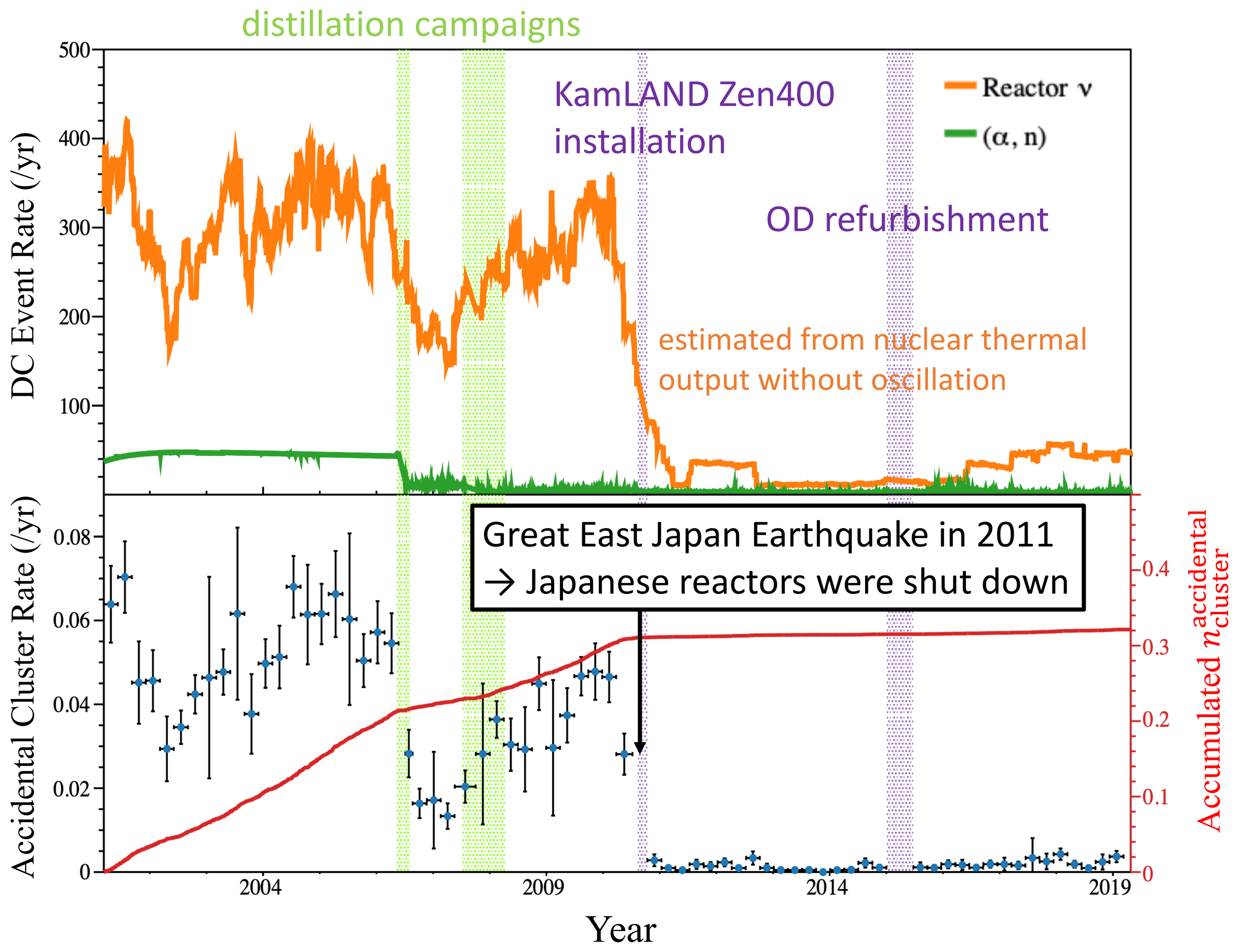
- Neutrino energy: (1.8–111) MeV
- Time difference between prompt & delayed event: (0.5–100) μs
- Vertex distance between prompt & delayed event: $\leq$ 160 cm



For SNν event

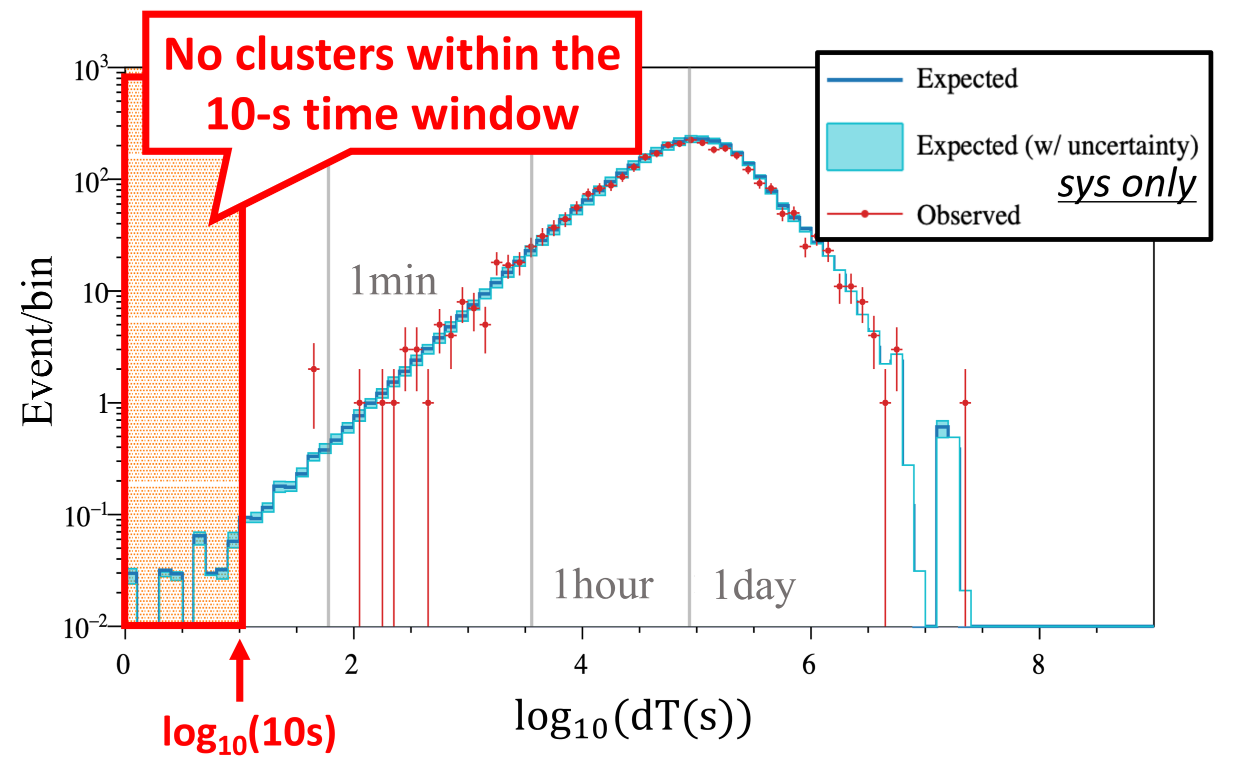
- Two DC events within a 10-s window

Expected number of accidental cluster:
$n_{\mathrm{cluster}}^{\mathrm{accidental}} = 0.32^{+0.02}_{-0.04}$



4. Analysis and result

We calculate the time difference between DC events and search for SNν events.



90% CL Upper limit (UL) on the

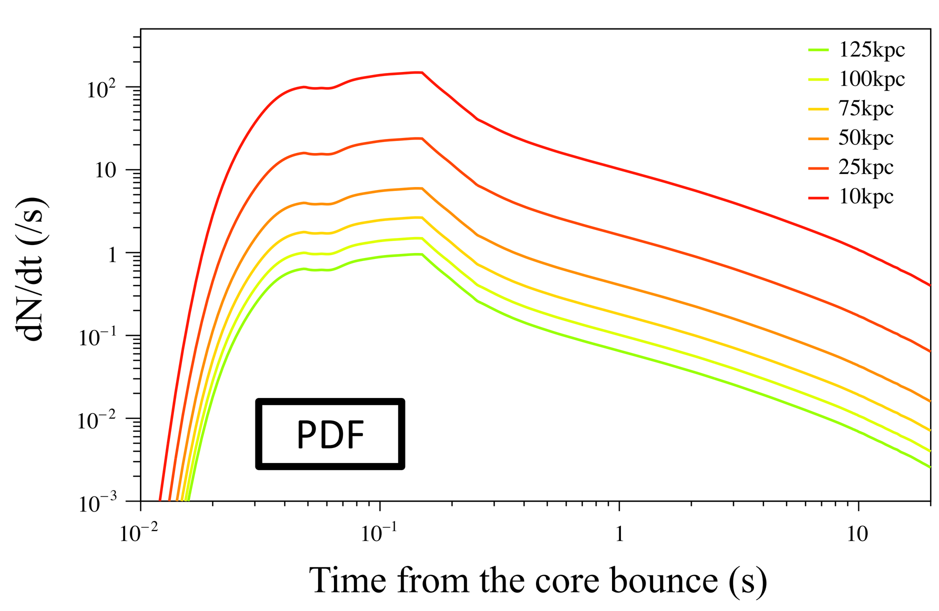
- Number of observed cluster: $n_{\mathrm{cluster}} < 2.1$ (Feldman-Cousins)
- Rate of observed cluster: $R_{\mathrm{cluster}} < 0.15\ \mathrm{yr^{-1}}$

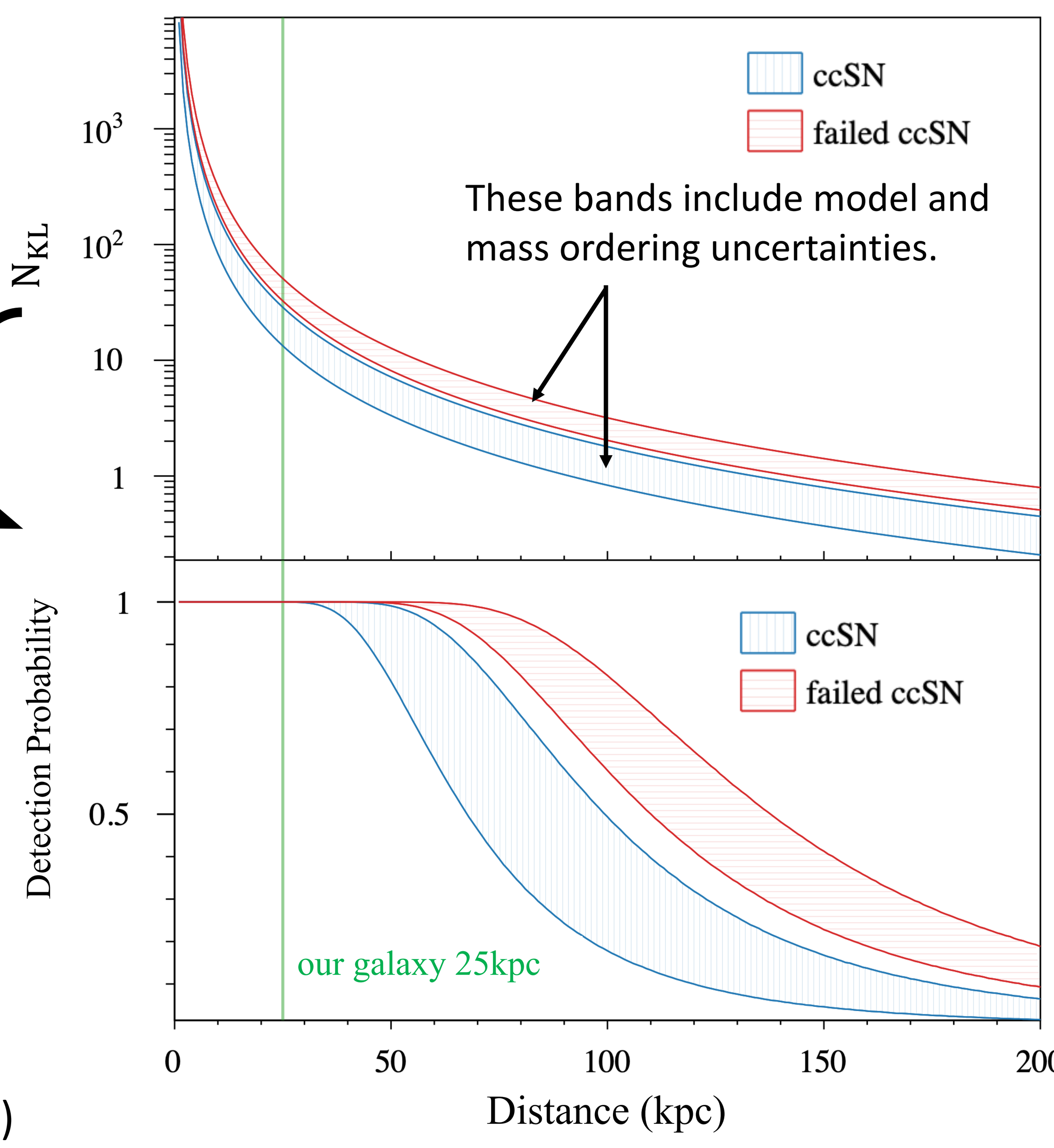
5. Discussion

Assuming that the clusters are originated from SN, we evaluate the detectable range of SNνs.
(Nakazato model [1] is used in this evaluation.)

MC based on the Poisson with mean N_{KL} and PDF was carried out.

Time distribution of SNν





Detectable range (detection probability $\geq$ 95%)

$\leq$ 40–59 kpc (ccSNe), $\leq$ 65–81 kpc (failed ccSNe)

This result gives an upper limit on the galactic ccSN and failed ccSN rate:

$R_{\mathrm{SN}}^{\mathrm{gal}} < 0.15\ \mathrm{yr^{-1}}$ (90% CL)

assuming that the SN rate on Large Magellanic Cloud and Small Magellanic Cloud are much smaller than the the galactic SN rate. [4]

[4]Tammann et al. 1994

There is a relation between galactic SN rate $R_{\mathrm{SN}}^{\mathrm{gal}}$ and galactic SFR $\psi_{\mathrm{SFR}}^{\mathrm{gal}}$ [5][6] :

$$R_{\mathrm{SN}}^{\mathrm{gal}} = k_{\mathrm{SN}} \psi_{\mathrm{SFR}}^{\mathrm{gal}}$$

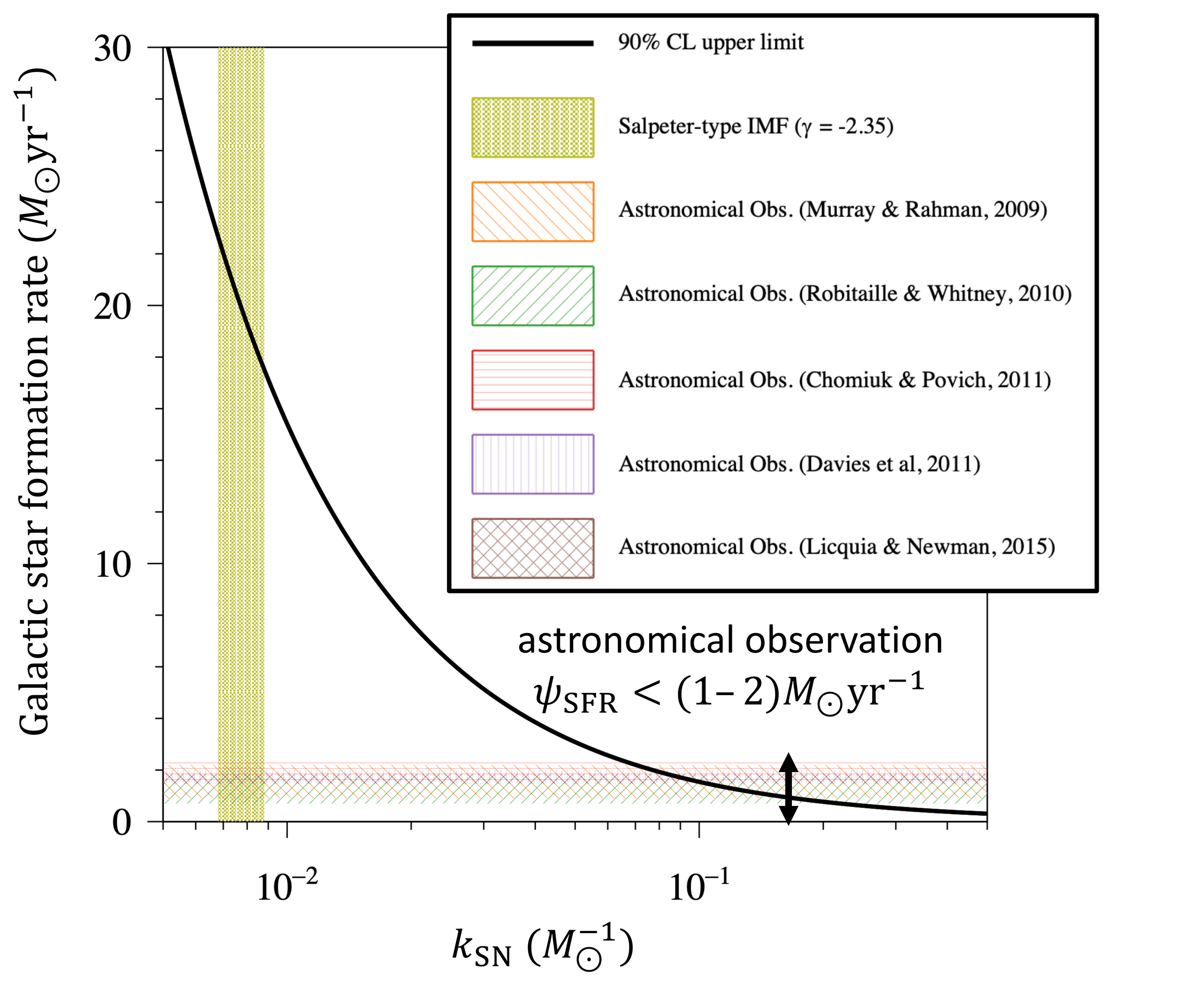
[5]Horiuchi et al. 2011
[6]Botticella, M. T. et al. 2012

$k_{\mathrm{SN}} = (0.0068\text{–}0.0088) M_{\odot}^{-1}$ is assumed by the modified Salpeter type initial mass function(IMF) [5][7][8] .

[7]Salpeter 1955
[8]Madau & Dickinson 2014

Our result provides the UL on the SFR:

$\psi_{\mathrm{SFR}}^{\mathrm{gal}} < (17.5\text{–}22.7) M_{\odot}\mathrm{yr^{-1}}$ (90%CL)



6. Summary and prospect

We searched for SNνs via the inverse beta decay with the KamLAND data.
We set an UL on the galactic SN rate and the galactic SFR.

SNνs search via the ^{12}C neutral current (NC) interaction is under the investigation.

Advantages: All flavors of neutrinos which have higher energy than energy threshold of ^{12}C NC would make peak structure around 15MeV.